Asian Journal of Water, Environment and Pollution, Vol. 3, No. 1, pp. 95-102.

Distribution of Planktonic Foraminifera in the Recent Subtropical Water Mass and their Comparison to the Surface Sediment: Implications for Palaeoenvironmental Reconstruction

Mia Mohammad Mohiuddin

Department of Geology and Mining
University of Rajshahi, Rajshahi 6205, Bangladesh
✉ mohiuddin@geologist.com

Received December 27, 2004; revised and accepted November 18, 2005

Abstract: A comparison between planktonic foraminifera assemblage in the sediment trap and those at core-tops located close to mooring in the subtropical Pacific was analyzed to assess the relationship between preserved faunal assemblages and the recent fluxes. At Station WCT-1, the total foraminiferal fluxes showed a seasonal variation, characterized by high flux value during summer and low in winter. The seasonal patterns for the two trap depths also showed a close similarity in both the number and magnitude of the peaks. Variation in the foraminiferal fluxes could be representing seasonality in the production of different foraminiferal species and reflect change in hydrographic conditions in the upper water column. Dissolution susceptible species, *G. ruber, G. glutinata, G. quadrilobatus* and *G. sacculifer* are abundant in surface water and dominated in the flux material. On the other hand, dissolution resistant species, *G. inflata, N. pachyderma* and *G. crassaformis,* increased their relative abundance in the surface sediment. The foraminiferal species differ between the trap and core-top assemblages and indicate that the sediments have been significantly altered since deposition. The comparisons between foraminiferal core-top assemblages from this region can therefore be directly related to modern sea-surface conditions, providing an analogue for interpreting past environmental change from fossil assemblages.

Key words: Planktonic foraminifera, sediment trap, surface sediment, subtropical pacific, palaeoenvironment.

Introduction

The planktonic components of microfossil assemblages in surface sediments reveal more specific information about the modern conditions of sea surface hydrography. The standing stock of planktonic foraminifers observed at a specific time and locality is the result of the interaction between biological (e.g. food supply) and physico-chemical factors (e.g. temperature, salinity, turbidity) (Bé et al., 1977; Hemleben et al., 1989; Ortiz et al., 1995). Every species is adapted to a certain range of these factors. The temporal and spatial variability of these parameters results in a patchy distribution of planktonic foraminiferal assemblages on various scales (Schiebel and Hemleben, 2000). Therefore, investigating correlations between surface-sediment distributions of planktonic microfossils and modern conditions of ocean hydrography can help develop useful proxy indices of microfossils for estimating past sea surface conditions. Furthermore, in order to better reconstruct paleoenvironmental changes using fossil foraminifera in sediments, the geographic distribution and ecology of living planktonic foraminifera as well as their settling to the seafloor must be known.

The time-series sediment trap, which directly collects settling particles in the water column, is an effective instrument to help understand the sedimentation processes for planktonic foraminiferal tests (Eguchi et al., 1999; 2003; Yamasaki and Oba, 2003; Mohiuddin et al., 2002, 2004). On the other hand, surface sediments contain indices of many environmental variables such as surface-, intermediate-, and deep-water conditions. The fossil record of planktonic foraminiferal assemblages in marine sediments is a key tool used by palaeoceanographers to study past environments (Chen et al., 1997; Xu and Oba, 1999; Mohiuddin and Nishimura, 2003). However, the fossil assemblages may be altered after deposition by processes including dissolution, bioturbation and resuspension. Recent study showed that the core-top assemblages of planktonic foraminifera in the modern ocean are directly related to sea-surface conditions, providing an analogue for interpreting past environmental change from fossil assemblages (King and Howard, 2001; 2003). Comparison of faunal assemblages in the core-top and sediment trap can also be used to determine the extent of post depositional changes in the sediment record as well as flux seasonality which significantly affect our interpretation of sedimentary assemblages.

Sediment trap studies allow critical review of some of the potential sources of variability in our interpretation of fossil assemblages. These may substantially change the faunal composition of an assemblage. Core-top assemblages from the northwestern Pacific region can therefore be directly related to modern sea-surface conditions, providing an analogue for interpreting past environmental change from fossil. In this study sediment trap and core-top assemblages are compared to determine whether post-depositional changes and flux seasonality significantly affect our interpretation of sedimentary assemblages.

Surface Water Hydrography

Study sites are located in the subtropical water masses. The sediment trap was deployed at the Subtropical Front (SAF) in the western north Pacific characterized by temperature and salinity between north and south of the SAF. Three major currents are important in the study region (Figure 1): the North Equatorial Counter Current flowing from east to west, the Subtropical Counter Current flowing west to east and Kuroshio Extension, a western boundary current of the subtropical gyre in the North Pacific, flowing along the shelf edge to the Okinawa Trough area and then continues flowing northeastwards until it reaches the Pacific Ocean south of Kyushu. During late winter to spring (January–April), the SST ranges from 22.6ºC to 23.9ºC, and gradually increases during the summer months, reaching a maximum of up to 30.08ºC in August. Temperatures at the end of May were unusually low due to changes in course of the warm Kuroshio Current system.

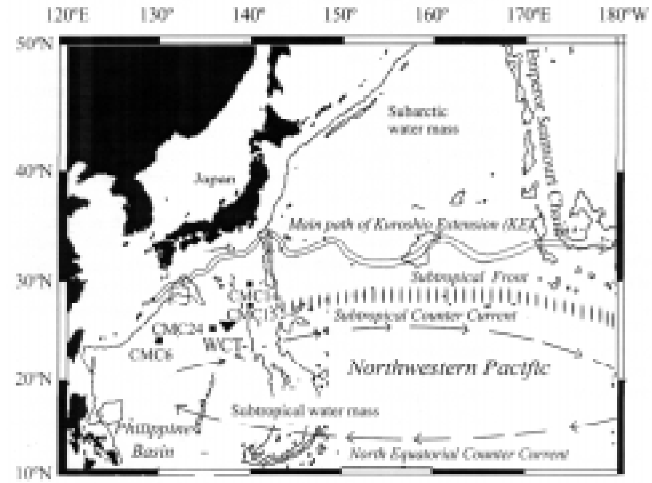

Figure 1: Location of the sediment trap station WCT-1 and multiple cores CMC 6, 14, 15 and 24 collected from the northwestern pacific. The main path of the Kuroshio Extension (KE) is based on Mizuno and White (1983).

Sample Collection

Sediment Trap

Sediment trap is a device of collecting settling particles in the ocean basin from different water depths. It has been widely used during the last two decades by chemical, biological and geological oceanographers. It also has been used to record the signs of seasonally changing primary production, such as spring blooms, knowledge of mechanism of transport of materials from surface water to deep water column and the role played by organisms and their product in formation of first sinking particles which arrive quickly and can have significant effects on the abyssal biota. For the present study, sediment trap samples were collected during cruise NH97 and NH98 of the R/V *Hakurei-maru*. Two trap cups were positioned at depths of 1060 m and 3930 m at Station WCT-1 (25º00.51´N, 137º01.12´E) (Figure 1), in the subtropical northwestern Pacific.

Surface Sediment

Four core-top samples from multiple cores were obtained from close vicinity of the trap station during the same cruises from different water depths (Table 1). Wet samples were soaked in water for several hours, followed by washing through a 0.062 mm sieve, dried and planktonic foraminiferal species greater than 125 mm size fraction was split into aliquots of 300 or more planktonic foraminifera that were identified and counted.

Results

The fluxes of planktonic foraminifera were measured over period of two years. The mean total foraminiferal fluxes of 1997-1998 and 1998-1999 were 166.7 tests m^{-2} day^{-1} and 227.7 tests m^{-2} day^{-1}, respectively. At least two periods of high total foraminiferal shell fluxes are recorded at this site. The highest planktonic foraminiferal flux value was recorded in late June to early July in 1997-1998 and in mid July in 1998-1999. The total foraminiferal shell flux patterns for the shallow and deep traps show a close similarity in both the number and magnitude of the peaks (Figure 2a and b). Foraminiferal fluxes in terms of mg m^{-2} day^{-1} also show a very low value. Flux rates do show direct mirror of the number of the planktonic foraminiferal specimens. Highest fluxing of $CaCO_3$ shell of planktonic foraminifera occurred during late June to early July. The lowest worst preservation of calcite was recorded during early half of January.

A total fourteenth planktonic foraminiferal species were identified in this site. Eight of these, *Globigerinoides ruber, Globigerinoides sacculifer, Globigerinoides quadrilobatus, Globigerinoides conglobatus, Globigerinita glutinata, Globorotalia scitula, Globigerinella calida* and *Globigerinella aequilateralis* occur in significant proportions and altogether account for more than 90% of total foraminiferal flux both in shallow and deep traps (Figure 3). At Station WCT-1, there were two periods of high flux during the period of experiment, one in January-February and the other in June-July. March to April is characterized by very low productivity of the total foraminiferal fluxes. *Globigerinoides ruber* is the most dominant planktonic foraminiferal species at this station. The flux value of this species ranged from 1.76 to 366.22 (56%) tests m^{-2} day^{-1}. This species constituted 23–18% of the total foraminiferal flux in 1998 and 33–38% in 1999. *Globigerinita glutinata* is the second-most abundant planktonic foraminiferal species, with a mean calculated flux from 35.7 to 28.6 tests m^{-2} d^{-1} (23–18%) in 1997–98, and 9.9–45.1 tests m^{-2} d^{-1} in 1998–99 (19–5%).

Globorotalia inflata is the dominant foraminiferal species in the surface sediment in this region and constituted approximately 6, 22 and 31% of the total at CMC 24, CMC 6 and CMC 15, respectively (Table 3). *Globigerina bulloides* constituted highest percentage at CMC 24 (approximately 33%), decreased at CMC 6 (approximately 6%) and very low percentage at CMC 15 (approximately 1%). Apart from these, three other species, *N. pachyderma, G. crassaformis* and *G.truncatulinoides* are also dominant in the surface sediment.

Discussion

Seasonality of Planktonic Foraminiferal Fluxes in the Surface Water

At Station WCT-1, the seasonal flux of total foraminifera at Station WCT-1 increased during the summer months. The total foraminiferal fluxes in shallow and deep traps showed similar distribution patterns during the period of observation. Two flux maxima occurred in 1997–98, with a higher peak during late summer (June–July) and a lower one in winter (January–February). In 1998–99, however, there were three maxima with the highest one in late June–early July, and others in late December and mid April, in both shallow and deep traps. Planktonic foraminifera showed a very low abundance in January–March in both years. The late summer peaks were associated with well-stratified warm surface layer (temperature 24–28ºC) (Figure 2). The seasonal variation in the flux of each species exists at Station WCT-1, with high fluxes of *G. glutinata, G. quadrilobatus* and *G. tenellus* in January-February, and *G. ruber* and *G. sacculifer* in June to July. The seasonal flux patterns of the planktonic foraminifera are clearly related to the various temperature habitats of different species.

In the surface water at Station WCT-1, the dominant foraminiferal species are *G. glutinata, G. ruber, G. sacculifer, G. tenellus* and *G. quadrilobatus.* All these species are ecologically similar, having obligate dinoflgellate symbionts and omnivorous feeders. Most of these species are spinose, shallow dwelling, having their general oceanographic characteristic of preferring high SST, low salinity and well-developed seasonal thermocline in the surface water. The maximum abundance of *G. glutinata* has been recorded in the upper 50 m in tropical/subtropical surface waters (Mohiuddin et al., 2002; Tedesco and Thunell, 2003). In the surface water, *G. ruber* is one of the abundant species in the central and eastern Pacific (Thunell and Reynolds, 1984; Thunell and Honjo, 1981; Mohiuddin et al., 2002). Based on its temperature preferences, this species associated with *G. sacculifer* is the true tropical species, which does not tolerate low temperatures (Bijma et al., 1990). Based on their temperature preference, these two species are regarded as tolerant species of oligotrophic condition in

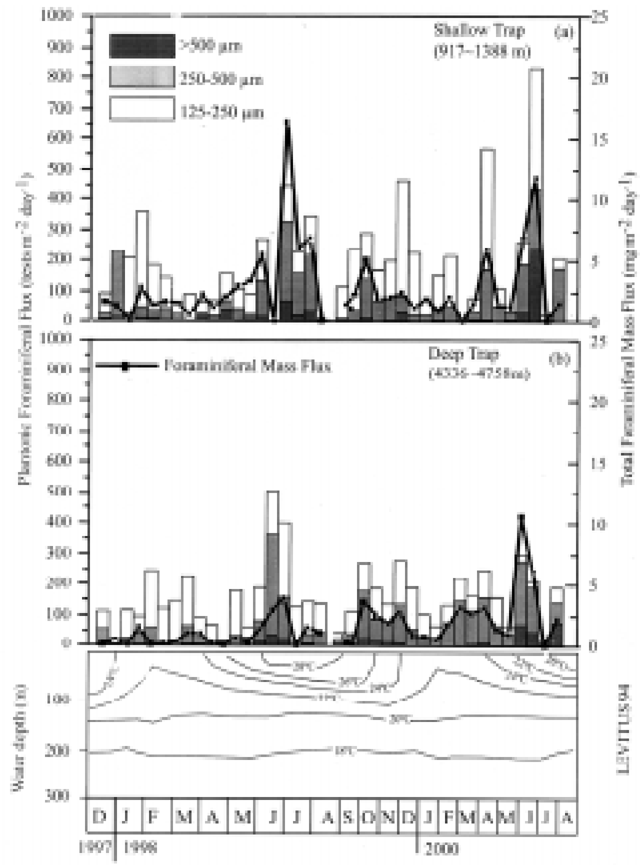

Figure 2: Seasonal distribution of total foraminiferal test and mass fluxes in the shallow (917-1388 m) and deep (4336-4758 m) traps at station WCT-1.

subtropical gyre water (Eguchi et al., 2003). Studies showed that *G. ruber* and *G. sacculifer* species prefer warm, stratified surface water condition (Bijima et al., 1990) and are abundantly present in tropical to subtropical oceanic provenances (Bradshaw, 1959).

Numerous studies suggested that *Globigerinoides* species (*G. ruber* and *G. sacculifer*) live within the surface mixed layer (Fairbanks et al., 1982; Watkins et al., 1996). These two species associated with *G. conglobatus, G. aequilateralis, G. tenellus* and *G. quadrilobatus* dominated the oligostropic stations in the central equatorial Pacific including the present station. Some mid-latitude winter species such as *G. truncatulinoides, G. inflata, N.* dutertrei and *G. bulloides* are associated with the Kuroshio Current at Station WCT-1, indicating that the Kuroshio Extension Current thus influenced this station during the period of observation. *Globorotalia scitula.* Salinity in the surface water of the subtropical Pacific varies within a narrow limit (34.7-34.9 psu), having a little effect on the seasonal distribution in this region which indicated that the seasonality of foraminiferal species is greatly controlled by temperature rather than salinity (Figure 3). Comparison of foraminiferal fluxes between the sediment trap and foraminiferal assemblage preserved in the surface sediment gives a clue of the depositional environment in the past. Sediment trap observation showed that the seasonality of planktonic foraminiferal fluxes in the deep trap was similar to those in the shallow trap at Station WCT-1. Thus, the planktonic foraminiferal tests were believed to settle vertically in this region.

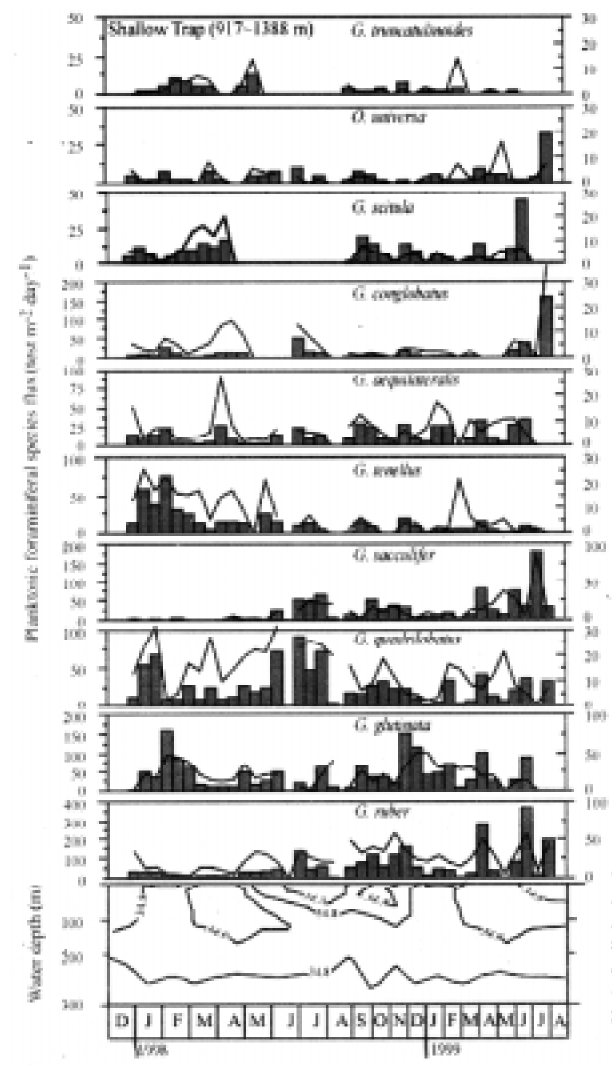

Figure 3: Seasonal variation of dominant planktonic foraminiferal species fluxes (bar) and relative abundances (line) in shallow trap (917 m) at station WCT–1. Different flux scale taxon by taxon should be noted.

Sediment Trap to Core-Top Comparison

Foraminiferal carbonate is produced in the surface waters of the oceans as the hard parts of these organisms. Association of planktonic foraminifera can be an important proxy of ecosystems in the geologic record. The production of foraminiferal tests, their deposition and preservation as biogenous carbonate on the ocean floor depends on whether foraminiferal carbonate particles have undergone dissolution while sinking through the water column or on the regimes where dissolution could occur. Differential settling velocity causes differential residence time of empty tests in the water column, and exposition of tests to dissolution. At the sea floor, the tests are again subject to dissolution and winnowing, and small and thin-shelled tests are preferentially removed until they are covered by sediment. According to a recent estimation of the global carbon budget (Milliman et al., 1999), only about 20% of the total planktonic foraminiferal carbonate production accumulates in deep-sea sediments; the rest dissolve either in the water column or at or near the sediment–water interface. Thus, the rate of sedimentation can be an important factor of the preservation of carbonates tests on the sea floor. As deep sea sediments often contain better records of relative abundance of planktonic foraminiferal species than absolute fluxes, patterns of relative abundance, rather than standing stocks of individual species can also be best-illustrated gradients of biological properties and circulation within the upper water column.

The differential preservation potential of planktonic foraminiferal tests influences the relative abundance of different species in sediment assemblages (Wu and Berger, 1989). Because foraminifera species are closely related to the geographical as well as their extent of dissolution in the water column during settling, their fossil records are useful as paleoceanographic indicators of past water circulation (e.g., Mohiuddin and Nishimura, 2004). The species composition of planktonic foraminifera in the core top sediment below the mooring varies considerably from that found in the estimated annual flux as derived from the sediment trap. The mid-latitude winter species such as *G. truncatulinoides, G. inflata, N. dutertrei* and *G. bulloides* are associated with surface sediments in this region, indicating that this region was influenced by the Kuroshio Extension Current during the period of deposition. On the other hand, the most dominant foraminiferal species in the surface water, *G. ruber, G. glutinata, G. quadrilobatus, G. sacculifer* and *G. tenellus* showed their low constituents in the surface sediment, indicated that there species are characterized by high dissolution susceptible to solution and are mostly dissolved during the processes of sedimentation.

Planktonic foraminiferal species recorded in the down-core at CMC 6 divided into three groups of assemblages since 15 Ka, indicated two episodes characterized by specific foraminiferal assemblages (Mohiuddin and Nishimura, 2003). Down-core record in CMC 6 clearly show warm water forms and those with higher affinity for warm than for cold waters were presented by *G. ruber, G. glutinata, G. tenellus, G. sacculifer, G. conglobatus, G. aequilateralis* and *G. quadrilobatus.* Generally cold water foraminifera included the followings: *G. bulloides, N. pachyderma, G. crassaformis, G. inflata* and *G. truncatulinoides.* The degree of affinity for warm and cold waters is not alike for all the species within each group. Presence of high percentage of *N. pachyderma* in the surface sediments on CMC 6 and 14 is an indication of period of temperature drop of the surface water and was also thought to be product of spring bloom in the surface water of the North Pacific water mass. Therefore, high abundance of *G. bulloides* on the sedimentary record at CMC 24 is an indication of upwelling in the Pacific Ocean.

Core-top sample at CMC 24 is characterized by relatively high abundance of *G. bulloides, G. ruber* and *G. glutinata.* The *G. bulloides* and *G. ruber* are abundant in the surface water with intensive upwelling oceanographic condition as observed in different ocean basin (Mohiuddin et al., 2004; Peeters et al., 2002). Because of their widespread distribution in the world oceans, these species are widely used as indicators of environmental changes in surface water conditions and, in particular, for palaeoceanographic reconstructions of upwelling intensity and monsoon system variability (Prell and Curry, 1981; Kroon and Ganssen, 1989). In the Pacific, the distribution of *G. glutinata* is mostly found in the subtropics (Bé, 1977), and in the Panama Basin, high fluxes of this species are associated with deep mix layer conditions (Fairbanks et al., 1982). *Globigerina bulloides* is a subpolar species living in cold and deep-mixing surface waters, and is also abundant in strong upwelling oceans over the monsoon regions of the Arabian Sea (Prell, 1984). The abundance of *G. bulloides* is also used as a measure of productivity in western Indian coastal upwelling areas (Naidu et al., 1992). As mentioned in the result section on the core-top samples the dominant planktonic foraminiferal assemblage includes *N. pachyderma, G. inflata, G. crassaformis* and *G. bulloides.* Among these species, *G. bulloides* is highly susceptible to dissolution while the other three are considered dissolution-resistant. *Globorotalia crassaformis* has a thick test and is more resistant to dissolution. Consequently, *G. crassaformis* should make up a greater proportion (>20%) in the surface sediment. Thus, the high abundance of dissolution species in the surface sediment explain the fact that the low resistance species are dissolved either in the water column during the settling process or in the sediment after deposition with the consequent enrichment of the dissolution resistance assemblage in the sediment deposited on ocean basin.

It is assumed that there are several factors that may create differential dissolution between the foraminiferal assemblages preserved in core-tops and the modern assemblages inhabiting the water column. Firstly, the core-top samples represent the average conditions over hundreds and sometimes thousands of years. These mean conditions may deviate from the modern conditions at the same sites. In addition, this study represents collection over one annual cycle, so we cannot evaluate interannual variability and its effect on foraminiferal fluxes. Secondly, the assemblages may have been altered since deposition. Recent study in this region showed that the sedimentation rate varies from 2.4 cm/1000Y to 10.4 cm/1000Y at CMC 6 and from 3.4 cm-4.9 cm/1000Y at CMC 15 (Mohiuddin and Nishimura, 2003). High sedimentation rate at CMC 6 may be an important factor to preserve foraminiferal particles from string dissolution effect. At Station WCT-1, the total foraminiferal flux estimated for shallow and deep traps reveal no significant decrease with depth, indicating that dissolution has not substantially altered the trap assemblages in the subtropical Pacific region (Figure 3).

Sediment trap observation at the present station showed distinct seasonality of total foraminiferal fluxes and the species composition and abundance of planktonic foraminifera deposited on the sea floor. A comparison of planktonic foraminiferal fauna from the sediment trap and core top samples is represented in Figure 4. In the surface water, *G. ruber* is the most frequent species, followed by *G. glutinata, G. quadrilobatus* and *G. sacculifer*. In the water column, dominant foraminiferal species experienced substantial changes as recorded in the trap material and as in the surface sediment. None of the foraminiferal species have been showing identical percentage in the surface sediment and the annual sediment trap, indicating that the sediments have been significantly altered since deposition. Since the sediment trap faunas represent the environmental variability in the northwestern Pacific, they also provide a good analogue for environmental interpretation of similar faunas deposited in the past.

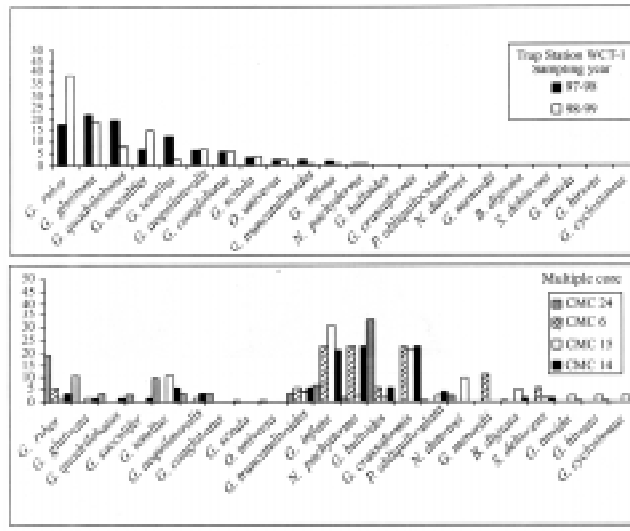

Figure 4: Comparison between foraminiferal assemblages at core-tops (CMC 6, 24, 14, and 15) and sediment trap at WCT-1 in the subtropical water mass in the northwestern pacific.

Acknowledgements

I thank Dr. Akira Nishimura and Dr. Y. Tanaka (Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology) to provide me trap and core-top samples for this study. Financial assistance for this study by AIST, MITI (Agency of Industrial Science and Technology, Ministry of International Trade and Industry, Japan) to the first author during the period of this work is gratefully acknowledged.

References

Bé, A.W.H. (1977). An ecological, zoogeographic and taxonomic review of recent planktonic foraminifera. *In:* Ramsay, A.T.S. (Ed.). *Oceanic Micropaleontology,* Academic Press, London, pp. 1-100.

Bijma, J., Faber, Jr., W.W. and C. Hemleben (1990). Temperature and salinity limits for growth and survival of some planktonic foraminifers in laboratory cultures. *J. Foraminifer. Res.* **20:** 95-116.

Bradshaw, J.S. (1959). Ecology of living planktonic foraminifera in the north and equatorial Pacific Ocean: Contributions of the Cush. *Found. Foraminifer. Res.,* **10:** 25-64.

Chen, M.-T., Huang, C-Y. and K-Y. Wei (1997). 25,000-year late Quaternary record of carbonate preservation in south China Sea. *Palaeogeography, Palaeoclimatology, Palaecology,* **129:** 155-169.

Cullen, J.L. and W.L. Prell (1984). Planktonic foraminifera of the northern Indian Ocean: Distribution and preservation in surface sediments. *Mar. Micropaleont.,* **9:** 1-52.

Curry, W.B., Ostermann, D.R., Guptha, M.V.S. and V. Ittekkot (1992). Foraminiferal production and monsoonal upwelling in the Arabian Sea: Evidence from sediment traps. *In*: Summerhayes, C.P., Prell, W.L. and Emeis, K.C. (eds.) Upwelling Systems: Evolution since the Early Miocene. Geol. Soc. Spec. Publ. **64:** 93-106.

Eguchi, N.O., Kawahata, H. and A. Taira (1999). Seasonal response of planktonic foraminifera to surface ocean condition: Sediment trap results from the central North Pacific Ocean. *J. Oceanogra.,* **55:** 681-691.

Eguchi, N.O., Ujiié, H., Kawahata, H. and A. Taira (2003). Seasonal variations in planktonic foraminifera at three sediment traps in the Subarctic, Transitional and Subtropical zones of the central North Pacific Ocean. *Deep-Sea Res.,* **48:** 149-163.

Fairbanks, R.G., Sverdlove, M., Free, R., Wiebe, P.H. and A.W.H. Bé (1982). Vertical distribution and isotopic fractionation of the living planktonic foraminifera from the Panama Basin. *Nature***,** **298:** 841-844.

Guptha, M.V.S., Curry, W.B., Ittekkot, V. and A.S. Muralinath (1997). Seasonal variation in the flux of planktic foraminifera: Sediment trap results from the Bay of Bengal, Northern India. *J. Foraminifer. Res.,* **27:** 5-19.

Hemleben, Ch., Spindler, M. and O.R. Anderson (1989). Modern Planktonic Foraminifera. Springer, Berlin, 363 pp.

Honjo, S. and K.W. Doherty (1988). Large aperture time-series sediment traps, design objectives, construction and application. *Deep Sea Res.,* **35:** 133-149.

Kawahata, H. (2002). Suspended and settling particles in the Pacific. *Deep-Sea Res.* **49:** 5647-5665.

King, A.L. and W.R. Howard (2001). Seasonality of foraminiferal flux in sediment traps at Chatham Rise, SW Pacific: Implications for paleotemperature estimates. *Deep-Sea Res. I,* **48:** 1687-1708.

King, A.L. and W.R. Howard (2003). Planktonic foraminiferal flux seasonality in subarctic sediment traps: A test for paleoclimate reconstruction. *Paleoceanography,* **18:** 19-1-19-17.

Kroon, D. and G. Ganssen (1989). Northern Indian Ocean upwelling cells and the stable isotope composition of living planktonic foraminifers. *Deep-Sea Res.,* **36:** 1219-1236.

Kuroyanagi, A., Kawahata, H., Nishi, H. and M.C. Honda (2002). Seasonal changes in planktonic foraminifera in the northwestern North Pacific Ocean: Sediment trap experiments from subarctic and subtropical gyres. *Deep-Sea Res.,* **49:** 5627-5645.

Levitus, S. and T. Boyer (1994). World Ocean Atlas 1994, Volume 4: Temperature, NOAA Atlas NESDIS 4, US Department of Commerce, Washington, DC. *http://ingrid.ldeo.columbia.edu/sources/.levitus94/*

Milliman, J.D., Troy, P.J., Balch, W.M., Adams, A.K., Li, Y.-H. and F.-T. Mackenzie (1999). Biologically mediated dissolution of calcium carbonate above the chemical lysocline? *Deep-Sea Res. I,* **46:** 1653-1669.

Mizuno, K. and W.B. White (1983). Annual and interannual variability in the Kuroshio Current System. Journal of Physical Oceanography, **13:** 1847-1867.

Mohiuddin, M.M. and A. Nishimura (2003). Down-core Variation of Planktonic Foraminiferal faunas in the NW Pacific and Their Palaeoenvironmental Implications during last 15 Ka. *Bangladesh Geoscience J.,* **9:** 31-46.

Mohiuddin, M.M., Nishimura, A., Tanaka, Y. and A. Shimamoto (2002). Regional and interannual productivity of biogenic components and planktonic foraminiferal fluxes in the Northwestern Pacific Basin. *Mar. Micropaleontol.,* **45:** 57-82.

Mohiuddin, M.M., Nishimura, A., Tanaka, Y. and A. Shimamoto (2004). Seasonality of biogenic particle and planktonic foraminifera fluxes: Response to hydrographic variability in the Kuroshio Extension, northwestern Pacific Ocean. *Deep-Sea Res. I,* **51:** 1659-1683.

Naidu, P.D., Babu, C.P. and Ch.M. Rao (1992). The upwelling record in the sediments of western continental margin of India. *Deep-Sea Res.,* **39:** 715-723.391- 403.

Ortiz, J.D., Mix, A.C. and R.W. Collier (1995). Environmental control of living symbiotic and asymbiotic foraminifera of the California Current. *Paleoceanography*, **10(6):** 987-1009.

Peeters, F.J.C., Brummer, G-J.A. and G. Ganssen (2002). The effect of upwelling on the distribution and stable isotope composition of *Globigerina bulloides* and *Globigerinoides rubber* (planktic foraminifera) in modern surface waters of the NW Arabian Sea. *Global and Planetary Change,* **34:** 269-291.

Perker, F.L. and W.H. Berger (1971). Faunal and solution patterns of planktonic foraminifera in surface sediments of the south Pacific. *Deep-Sea Res.,* **18:** 73-107.

Prell, W.L. (1984). Monsoonal climate of the Arabian Sea during the late Quaternary: A response to changing solar radiation. *In:* Berger, A.L., Imbrie, J., Kukla, G., Saltzman, B. (Eds.), Milankovitch and Climate Part 1. D. Reidel, Dordrecht, pp. 349- 366.

Schiebel, R. and C. Hemleben (2000). Interannual variability of planktic foraminiferal populations and test flux in the eastern North Atlantic Ocean (JGOFS). *Deep-Sea Res. II*, **47:** 1809-1852.

Tedesco, K. and Thunell, R.C. (2003). Seasonal and interannual variations in planktonic foraminiferal flux and assemblage composition in the Cariaco basin, Venezuela, J. *Foraminifer. Res.* **33:** 192-210.

Thunell, R. and L.A. Reynolds (1984). Sedimentation of planktonic foraminifera: Seasonal changes in species flux in the Panama Basin. *Micropaleontol.,* **30:** 243-262.

Thunell, R.C. and S. Honjo (1981). Planktonic foraminiferal flux to the deep ocean: Sediment trap results from the tropical Atlantic and the central Pacific. *Mar. Geology,* **40:** 237-253.

Watkins, J.M., Mix, A.C. and J. Wilson (1996). Living planktic foraminifera: tracers of circulation and productivity regimes in the central equatorial Pacific. *Deep-Sea Res., II* **43:** 1257-1282.

Wu, G. and W.H. Berger (1989). Planktonic foraminifera: Differential dissolution and the Quaternary stable isotope record in the west equatorial Pacific. *Paleoceanography,* **4:** 181-198.

Xu, X. and M. Oba (1999). Surface-water evolution of the eastern East China Sea during the last 36,000 yeaars. *Mar. Geology,* **156:** 285-304.

Yamasaki, M. and M. Oda (2003). Sedimentation of plaktonic foraminifera in the East China Sea: Evidence from a sediment trap experiment. *Mar. Micropaleontol.,* **49:** 3-20.